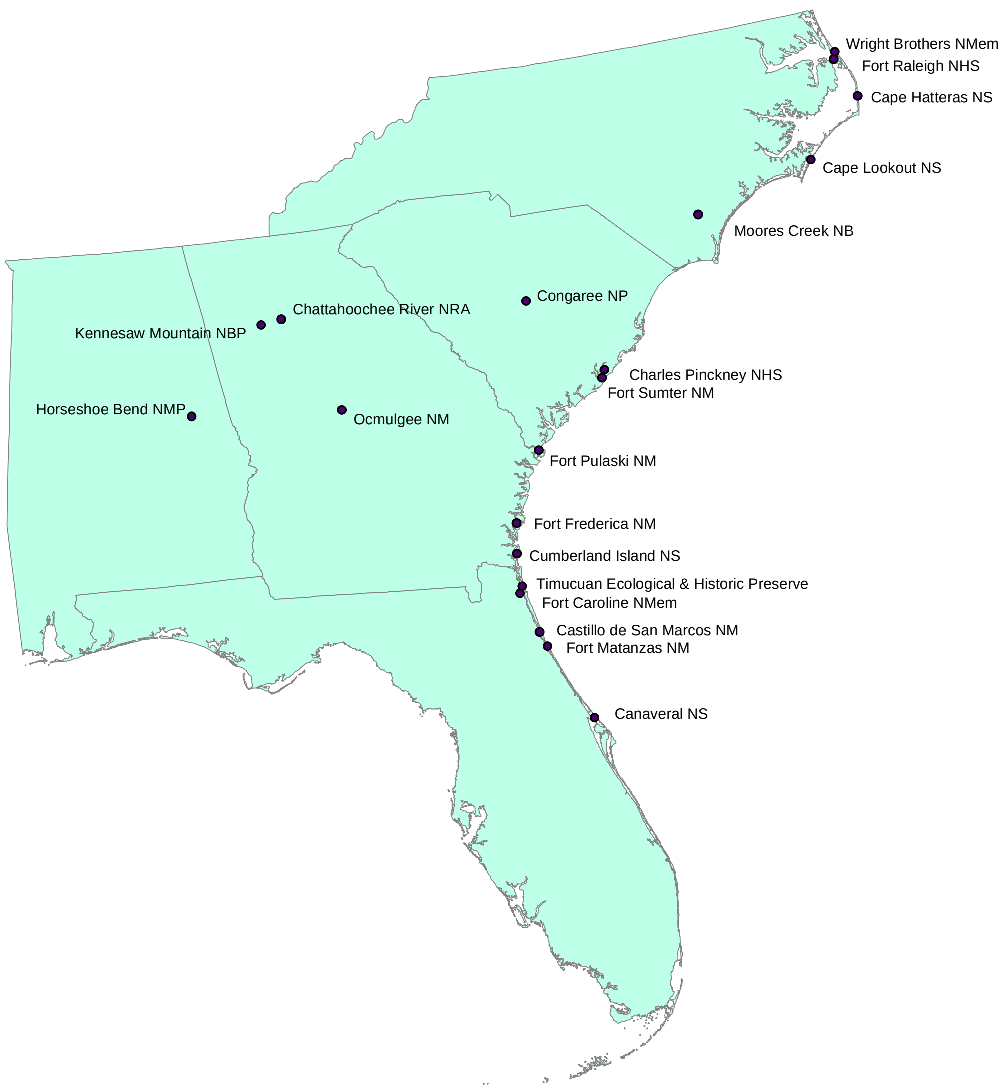
National Park Service
U.S. Department of the Interior

Southeast Coast Network
Atlanta, Georgia

Appendix 4 – Methods for Vital Signs Selection within the Southeast Coast Inventory & Monitoring Network



Joseph C DeVivo, National Park Service
Clifford J. Carrubba, Emory University

Suggested Citation:

DeVivo, J. C., and Carrubba, C. J. 2004. Appendix 4 – Methods for Vital Signs Selection within the Southeast Coast Inventory & Monitoring network. *In* Vital signs monitoring in the Southeast Coast Inventory & Monitoring Network - Phase III (draft) Report. National Park Service, Southeast Coast Network, Atlanta, Georgia.

Revision History

Date	Description
30 August 2004	Submitted with final version of the Phase I Report.
15 May 2005	Submitted with final version of the Phase II Report. Revised based on reviewers' comments following submission of Phase I report and after using the process to select the SECN vital signs.
07 August 2006	Draft Phase III version.

Table of Contents

Executive Summary

1. Ecological monitoring programs are often based on indicators because of their ability to provide relevant information in an efficient and cost effective manner. Although much study has been conducted to define characteristics of good indicators, little to no research has been conducted on appropriate methods for selecting indicators when multiple choices exist.
2. The National Park Service is currently developing an indicator-based long-term monitoring program designed around two principles: (a) Parks must coordinate efforts within "networks" of parks with similar ecosystems to efficiently share resources and (b) Resources are a fraction of what is likely to be necessary for adequate monitoring.
3. Given budgetary and staffing constraints, each network of parks must select one or more indicators to monitor that will provide the most relevant information to the greatest number of parks.
4. Because each network faces a situation of limited resources and resource sharing, the <u>method</u> of indicator selection needs to be evaluated to ensure the most efficient program design.
5. We propose using an economic-based (resource allocation) model for selecting indicators rather than one based solely on scientific merits of individual indicators. Welfare Maximization is an appropriate model in the case of monitoring program design when multiple partners with varying program needs are involved.
6. The underlying principle is to identify a suite of indicators, or multiple suites of indicators, that can only be modified to provide more useful information for one Park if the remaining parks receive less-useful information. This ensures that within programmatic constraints, an efficient program design will be selected that is of greatest benefit to all Parks.

Background & Objectives

During the last twenty years indicator-based monitoring programs have been developed to assess almost every ecosystem type around the world. Recent syntheses have focused on topics such as qualities of "good" vs. "bad" indicators, statistical sampling design, and methods to integrate monitoring programs with adaptive management programs—all in an effort to ensure that new programs meet desired objectives (Busch and Trexler 2003). However, to date no adequate discussion has occurred about methods for selecting *what* indicators to monitor in the context of an integrated monitoring program when multiple options exist. The need to select indicators based on sound, defensible methods is critical to program success, particularly as new monitoring programs are intended to support an increasing number of management goals for an increasing number of partners.

Congress charged the National Park Service (NPS) to manage natural resources on NPS lands based on sound science (Pub. L. 105-392). The NPS Inventory & Monitoring Program was developed to implement this directive by acquiring baseline information and developing and implementing long-term ecological monitoring programs at all NPS units with significant natural resources. To implement this plan, the NPS has grouped park units with significant natural resources into 32 networks nationwide and is phasing in funding and development of monitoring programs over the course of a five year span (National Park Service 2003). To date only twelve networks have completed the process of identifying natural resource issues on their respective parks and selecting indicators around which to design long-term monitoring programs (Milstead and Stevens 2003;Emmott et al. 2003;Hubbard et al. 2003;Leibfreid 2003;Welch 2003;Weber 2003). The Southeast Coast Network (SECN), located in the southeastern United States, is in the third "wave" of funding, and is just embarking on the design of its integrated monitoring program.

Although each network is responsible for developing an integrated monitoring program among all parks within the network, several issues must be considered in the design of the program. First, each network is funded at levels significantly below that which is expected to be needed to meet all of the needs of member parks. Congress intentionally made this decision to encourage the National Park Service to design efficient programs and seek outside partners with which funds and efforts could be leveraged. Consequently, each Network must develop an indicator-based monitoring program whereby several information-rich indicators are chosen for monitoring because they are relevant to multiple natural resource issues, parks, or components within park ecosystems. The National Park Service refers to these indicators as "Vital Signs" because like the measurement of blood pressure for a sick patient, Vital Signs are intended to give an indication of the overall health of the natural resources.

Second, those resources are intended to be shared among several parks that share the common NPS mission, but are faced with very different management directives across a wide range of ecosystems. The SECN contains twenty parks, seventeen of which contain significant and diverse natural resources that in total encompass more than 178,000 acres of federally-managed land across North Carolina, South Carolina, Georgia, Alabama, and Florida. The parks range in size from slightly more than 20 to nearly 60,000 acres, and when considered with non-federal lands jointly managed with SECN parks the Network encompasses more than 242,000 acres. At the same time, SECN parks span a wide diversity of cultural missions as well, including four National Seashores, two National Historic Sites, two National Memorials, seven National Monuments, two national Military Parks, as well as a National Recreation Area, National Battlefield, and Ecological and Historic Preserve. Although the ultimate monitoring program is required to be explicitly tied to park management issues, each park within the Network necessarily has different priorities for both the management and monitoring of natural resources.

Two critical facts – that the networks are operating under significant budget constraints, and that the scarce resources necessary for the parks and networks to achieve their goals are being allocated from a common pool – necessarily mean that the procedures by which decisions over resource allocation are made will be as important as the actual ecological priorities themselves. That is, the same set of ecological priorities will lead to more or less efficient resource allocation decisions depending on the decision-making procedure. Thus, without careful consideration of the decision-making procedures, in all likelihood resources will be substantially under-utilized (Morrow 1994).

The purpose of this paper is to present a new method for selecting ecological indicators for a monitoring program that is shared among multiple park units within the National Park Service Inventory and Monitoring Program, each of which has different, but similar, management objectives. To do this, we will:

- Summarize methods, assumptions, and lessons learned by other networks in the NPS Inventory & Monitoring program,
- Present an alternative method for evaluating and selecting indicators in a monitoring program, and
- Discuss the method's utility in the context of adaptive management and long-term program development.

Lessons Learned: NPS Selection of Vital Signs

Each network is following a general four-step approach to developing its monitoring program including (a) identifying and stating the goals of the monitoring program, (b) developing conceptual models that describe ecosystems and link the components and processes within them, (c) identifying potential indicators that can be used to gain relevant information about the status and trends of those ecosystems, and (d) selecting final vital signs from the list of candidate indicators. These steps are consistent with Busch and Trexler's (2003) recommendations for designing and implementing an ecological monitoring program.

Two primary products are developed during the program design process: a list of specific monitoring objectives that are relevant to one or more parks within the network, and a second list of potential indicators that can be monitored to meet those monitoring objectives. In both cases the identification of questions and potential indicators lists are developed through a combination of literature review, expert opinion, conceptual modeling, and public scoping meetings. Potentially, the second list includes hundreds or thousands of potential indicators, only a small fraction of which will ultimately be chosen for Vital Signs monitoring.

Paring down the lists of indicators has been done following one or more of several methods including criteria matrices, consensus building, and BOGSAT (bunch of guys / gals sitting around a table). Other model-driven approaches include analytic group decision making / analytic hierarchy process (Schmoldt and Peterson 1997;Schmoldt and Peterson 2000). These methods have been implemented using a combination of computer software packages (such as Delphi) and facilitated meetings (Table A4-1). In all cases, the focus has been on describing qualities of candidate indicators and subsequently scoring and prioritizing those indicators based on those qualities (Table A4-2) (Jackson et al. 2000;Kurtz et al. 2001;Dale and Beyeler 2001). The strategy is based on selecting those monitoring variables that are most relevant to management concerns, logistically feasible, responsive to perceived threats and stressors, and easy to interpret and apply to environmental decision making.

Overall program design is then accomplished by selecting final vital signs from the a prioritized list to the extent that budgetary and logistical constraints allow. This method can potentially lead to a suite of vital signs that are biased toward one scale, technology, faunal group, etc., and a round of "horse trading" ensues until consensus is reached on a final set of Vital Signs. Although "horse trading" might result in a much more appropriate list of vital signs, the methods by which changes are made can be haphazard at best, and arbitrary at worst. Reasons for moving indicators up or down on a priority list might not be documented. Further, although a consensual decision-making procedure may have intuitive appeal, it is important to recognize that this procedure by no means will yield the most efficient (or even *an* efficient) allocation of resources. The actual allocation will depend heavily upon the specifics of the "horse-trading," such as who is in a position to make proposals, what alternatives are considered, and in what order (Morrow 1994).

Review methods implemented to date suggests that Vital Signs selection to date has been accomplished based on two assumptions: (1) characteristics of individual indicators should drive monitoring program design, and (2) measurement of a single indicator provides sufficient information on which to base management decisions.

Assumption 1: Characteristics of Individual Indicators Should Drive Program Design

Although attributes of individual indicators can be important when selecting indicators (such as scale, known or hypothesized responses to agents of change) at least two reasons exist for <u>not</u> using them as ranking criteria for potential indicators. First, ranking based on indicator characteristics (Table A4-2) is inherently flawed because individual indicators are evaluated based solely on the scientific / technical merits of the indicators themselves. However, a "best" indicator must also be based on a measure of how efficient it is at meeting goals of the entire monitoring program; a measure that necessarily changes depending on what *other* indicators are measured.

Second, because multiple objectives exist and because (in some cases) multiple vital signs can be used to meet those objectives, the value of a given indicator can increase or decrease depending on what else is being monitored. For example, benthic macroinvertebrate community diversity is often used as an indicator of water quality (Barbour et al. 1996;Resh et al. 1996). The value of benthic macroinvertebrate monitoring could be vastly different depending on whether relevant monitoring objectives are being met by measuring one or more other indicators of water quality (such as measuring water chemistry directly.

Viable indicators include those that can be used to answer specific monitoring questions at specific spatial and temporal scales given the current state of scientific knowledge. The criteria listed in Table A4-2 are more useful at determining whether a particular indicator should be considered in the first place – if potential indicators are too costly, logistically difficult, etc.; they do not meet the minimum requirements for inclusion in an indicator-base monitoring program.

When the process of vital sign selection is driven entirely by the qualities of individual indicators, there is a risk of losing sight of the monitoring objectives and issues those indicators are trying to address – it ceases to be a goal-driven process. More important is the risk of ignoring which monitoring objectives are of highest importance, and to whom.

Assumption 2: Measurement of a Single Indicator Provides Sufficient Information

The concept identifying one indicator to answer one or more monitoring questions is often thought to be the end goal of an indicator-based monitoring program. As a result, indicator selection necessarily focuses on the relative technical ability of any given indicator to meet one or more monitoring objectives. The traditional approach is therefore to identify indicators that are correlated with one or more components within an ecosystem, have known variances, and predictable responses to perturbations (natural and anthropogenic).

Although the statistical characteristics of any given indicator are important, it is equally important to note that indicators are seldom evaluated alone; those indicators are usually reported in the context of corollary data such as land use, season, etc. In fact many indicators *increase* in value because spatial and temporal variance can be explained through modeling two or more vital signs concurrently (Wenner et al. 2004). Many indicator-based monitoring protocols are themselves collections of indicators. For example, the methods discussed above of determining water quality based benthic macroinvertebrate communities in fact include a suite of indicators such as total taxa found, number of sensitive species found, number of taxa within sensitive groups, etc. Furthermore, the methods require a minimum level of habitat measurements, which are themselves indicators.

Consider the medical metaphor upon which the NPS Vital Signs monitoring program is based. Although a single vital sign might provide enough information to suspect that a problem exists, only in extreme cases does it properly diagnose what the specific medical problem might be (when the patient's heart rate reaches zero, everyone knows what the problem is!). However, a doctor would never rely solely on blood pressure data to diagnose a medical problem, and certainly wouldn't prescribe a treatment without more information such as a case history and / or lab tests.

Ideal indicators therefore, are those that not only provide an early warning for potential problems, but also allow managers to develop a "case history" of the ecosystem when considered in an integrative manner. In essence, individual indicators serve to both detect problems, and provide some level of context when trying to answer specific monitoring questions. Better indicators are those that provide context to multiple monitoring questions.

The Need for Another Method

Given the conditions of limited resources, and the need to divide those resources among multiple partners, resource allocation is as much dependent on the *process* as it is on the criteria for dividing those resources (Kreps 1990). The fact that all of the networks had some hesitation with their final lists of vital signs from a programmatic perspective (although individually scientifically sound) suggests that the processes used for Vital Sign selection might not have been ideally suited to the design challenge. More appropriate would be a selection method that explicitly accounts for:

- Assessing indicator utility based on synergism or redundancy with other indicators, in addition to technical merit. This implies focusing on *suites* of indicators rather than individual indicators.
- Focusing on the ability of those suites of indicators to meet monitoring objectives. This requires incorporating individual Parks' needs and priorities into the decision-making process as well as in identifying the list of potential indicators to be implemented.
- Incorporating sociopolitical or other non-technical factors into the decision-making process in a formal and documentable manner.
- Developing methods for generating alternative choices, all of which (a) meet minimum standards and needs of all Parks within a network, and therefore (b) represent viable choices for implementation.
- Providing a framework for selecting alternatives, and modifying those choices at a later time.

Welfare Maximization Model for Indicator Selection

The decision-making process that follows addresses the needs identified above, and is based on Bator's (1957) economic model designed to determine the best and most efficient distribution of multiple products to multiple constituents given limited resources. The underlying principle is to identify how an altruistic agent, who perfectly incorporates the interests of all of the relevant actors, would choose to allocate the existing resources. By doing so, the model identifies one or more solutions that cannot make any one actor better off without making the group as a whole worse off. The model has been modified for multiple applications such as to advise crop rotation planning, company expenditures, and distribution air pollution credits (Bator 1957;Mclure 1968;Laudadio 1971;Grabowski and Mueller 1972). In each case the authors created a model to guide production levels that is inherently linked to both individual customers' preferences, and production costs.

Welfare Maximization is a three-step process:

1. <u>Maximizing Production Efficiency</u>. All possible combinations of resource allocation such that an increase in production of one product necessitates a decrease in production of another. Allocations that meet this criterion maximize production efficiency within budgetary or other resource constraints.
2. <u>Maximizing Product Utility</u>. Based on customers' preference, identify those resource allocations such that an increase in satisfaction for one customer necessarily decreases the satisfaction of one or more other customers.
3. <u>Defining Constrained Bliss</u>. From the combinations of production that both maximize production efficiency and utility, select the one production function that best meets the welfare of all customers. In this case, welfare is defined by the ethic of the group to whom the products are intended (*not* necessarily scientific).

For the purposes of monitoring program design, the model needs to be modified slightly such that the program is designed to meet specific monitoring objectives (the "products"), for fifteen Park units (the "customers") with differing preferences for those products. In such a program the Network will implement monitoring protocols (collection of indicators) designed to answer to meet those monitoring objectives (Figure A4-1). A successful Vital Signs Monitoring Program under this model will be a balance of indicators (the "costs" of production) that maximizes the total number and the number of high priority objectives at all parks.

Pivotal to the process are two explicit qualifications. First, all protocols must be related to one or more specific monitoring questions identified by at least one park within the network. Second, protocols may consist of single indicators or collections of indicators.

Given this framework, monitoring program design proceeds as follows:

1. <u>Maximize Monitoring Efficiency</u>: Identify all possible suites of indicators that can be implemented within varying budget or staffing constraints. At this point, each suite is a potential monitoring program. If one or more of the indicators can be removed from a suite without reducing the *number of objectives* met, the combination of indicators is inefficient and not considered further. The resultant set represents potential programs that maximize production efficiency.
2. <u>Maximize Information Utility</u>: Based on parks' priorities for receiving answers to specific monitoring questions, select from the set of efficient program possibilities those combinations of protocols that maximize (a) the total number of objectives met, (b) the number of high-priority objectives met, and (c) average priority level of objectives met *for each individual Park* (Figure A4-2). At any given budgetary level, the resultant suites of indicators represent monitoring programs that can be implemented. In each case implementation of any of the alternative options would satisfy the needs and expectations of all Parks in the most efficient means possible.
3. <u>Choose the Most Relevant Alternative</u>: Select one option from the alternative potential programs for implementation based on qualities deemed important to the Parks and other stakeholders. This step assumes that although all potential alternatives represent desirable outcomes, some might be more

relevant than others. Selection criteria can include scientific, social, or political considerations, and can be explicitly documented. This step is particularly suited toward a consensus-building process because regardless of the outcome, all parties are guaranteed a program that maximizes both utility and efficiency.

Maximizing Monitoring Efficiency

Identifying efficient potential monitoring programs is a two step process that includes conducting a (near) complete inventory of potential questions that might be answered by a monitoring program, and an estimate of indicator costs and overall budget constraints.

Step 1: Identify and Monitoring Objectives

Each park within the network has identified specific resources or management issues of interest, and factors that either drive or alter those resources over space and time. In each case a specific monitoring objective can be. Collecting data and generating reports that meet those monitoring objectives are the primary "products" of the Network. For example, one of the questions of interest to all parks within the Southeast Coast Network is to determine the extent to which exotic plant management efforts are successful in meeting desired management objectives. Meeting that monitoring objective based on collection and analysis of data from one or more indicators, would then be a product of value to multiple parks within the Network.

Generating a comprehensive list of potential monitoring is the first step in data gathering. To accomplish this, the SECN augmented the park-derived monitoring objectives with all monitoring questions included in the first twelve network's Phase I and Phase II reports and associated appendices (Milstead and Stevens 2003;Emmott, Murdock, and Ranney 2003;Hubbard, Mau-Crimmins, Powell, Albrecht, Chambers, and Carder 2003;Leibfreid 2003;Welch 2003;Weber 2003). Where appropriate, monitoring questions were also included from the US Environmental Protection Agency's (2003) *Report on the Environment*, which included a list of monitoring questions applicable at the national scale.

It is important to note that the value of any given product might differ among the parks. In the above example, a park that has only a few exotic plants would have a very different use for the answer to that question than a park with multiple large populations of exotic plants and an active exotic plant management program.

Step 2: Estimate implementation costs of potential indicators

The basic unit of production is the measurement, analysis, and reporting of data collected while monitoring an indicator. Inherent in any given indicator therefore, is a measurement of field time, personnel requirements, data analysis and reporting time, and other associated costs related to implementation. Any one of those factors can be a constraining resource for the network. Although the data, analysis, and reports can be considered as useful products to some individuals or organizations (including the Parks within the Network), for the purposes of the model they are not considered to be products of the Network. During the initial stages of planning, costs must be estimated, and can later be refined as more information is gathered.

Maximizing Information Utility (Generate Alternatives)

Generation of program alternatives is a five-step process, the goal of which is to identify suites of indicators that when considered <u>as a group</u>, answer the greatest number of questions (and high-preference questions) at all parks.

Step 1: Conduct Preference Analysis

The primary customers of the Monitoring Program are the parks that depend on the information to make management decisions. The decisions of *what to monitor* and *where to monitor* are therefore entirely driven by the needs of the parks, which are expected to vary.

Each monitoring objective must then be evaluated by every park to assess its relevance for managing natural resources. This is critical not only from a modeling standpoint, but because national program priorities dictate that the monitoring program is to be designed to address issues of highest priority on each park. To accomplish the assessment of preferences, monitoring questions are categorized into six relatively broad categories ranging from “mandated” to “not the responsibility of the Park” (Table A4-3). Also included is a category for “Not Applicable” to account for those monitoring questions that relate to resources that a given Park does not have such as coast resources at an inland park.

Other stakeholders obviously exist with interest in the program for a variety of purposes. These might include other state and federal agencies, academic institutions, regional and national offices within the Park Service, local partners, the general public, and others that might have use for the data and summary reports. Although information, reports, and data summaries might be tailored and delivered routinely to one or more of these stakeholders, the needs of these stakeholders are not incorporated into the decision-making process at this point.

Step 2: Identify Protocols that can be Implemented

In theory, each monitoring objective can be addressed by monitoring one or more combinations of indicators; each combination of indicators representing a potential monitoring protocol. Identification of potential protocols is critical for assessing the degree to which individual indicators are able to help meet monitoring objectives. Linkages between indicators, protocols, and monitoring objectives are identified through a combination or literature review, conceptual modeling, and expert opinion.

Often, many combinations of indicators exist that can meet monitoring objectives that are similar, or variations of one another. When multiple options exist, the challenge is to identify the *minimum* number of indicators that can be implemented.

If no protocols exist (either existing or hypothesized) for meeting a monitoring objective, then the objective is removed from consideration. However each protocol might be applicable to meeting multiple monitoring objectives. Therefore, after identifying potential protocols are developed or identified each protocol is scored based on its ability to meet each of the monitoring objectives under consideration.

Step 3: Calculate Options

If park-specific preferences for monitoring objectives and the degree of applicability of monitoring protocols are determined as described, it is a relatively simple calculation to determine the degree of information richness of any given indicator at any given park through matrix multiplication (mathematical treatments are discussed below). Indicator costs can then be estimated based on the number of parks at which a particular indicator would be measured, if implemented, and number of staff members that would be needed to implement relevant protocols.

All possible combinations of indicators can then be evaluated based on total implementation costs (personnel and budgetary) as well as the number and priorities of the objectives addressed. This is done by summing the individual indicator costs as described above. Because of the large number of possible combinations of indicators (literally millions), this step needs to be automated using computers.

Step 4: Programmatic Checks

Each suite of indicators then needs to be assessed to ensure that it meets minimum programmatic goals based on criteria such as those listed in Table A4-4. A course filter should be applied that removes any combinations that that do not include the measurement of required indicators, or those that omit monitoring at one or more parks. Thresholds can be set for minimum number of questions answered per park, minimum number of high priority questions at each park, or the maximum number of staff required to implement the suite. Also, “Program Relevance Scores” can be calculated for each park by summing the preference scores for all questions that would be answered at each park. These calculations can be completed during the generation of program options, and anything that does not meet minimum programmatic goals can be eliminated from consideration.

Step 5: Indicator Utility Assessment

Maximization of overall indicator utility for all parks is the key principle of using a welfare maximization model (Bator 1957). If an indicator can be <u>removed</u> without changing the Program Relevance Scores for any of the parks, the entire combination is therefore removed from consideration. The concept is that if a particular indicator fails to add enough information to answer a particular monitoring question, its inclusion in a final monitoring program is an inefficient use of resources. This is a fundamental difference in approach from other methods of vital sign selection. In every other case, decisions about whether or not to include indicators were based on the characteristics of the indicators themselves (see Table A4-2), as opposed to their relationship to one another or their utility to individual parks within their network.

Choosing Alternatives

The process described above should yield several alternatives for suites of indicators that could be implemented as Vital Signs in a monitoring program. Every one of the options that is considered from this point forward represents a potential program that will meet <u>all</u> of the goals set forth by the Network, with clearly defined expectations and benefits for each park. If multiple options exist (which is likely), a preferred alternative should be selected based on a consensus-building process among the parks within the network, and regional and national program leads with a stake in the final selection of vital signs. Cost estimates should be revised for each candidate program based on the protocols dictated by the indicators measured.

At this point it is appropriate to consider factors such as social and political ramifications for measuring (or not measuring) an indicator, staffing implications, logistics, equitability among parks, balance of time scales and spatial scales among the indicators, or any other mutually-agreed upon criteria upon which to arrive at an alternative to move forward with (Table A4-4).

Conclusion & Discussion

Other Economic Models

Welfare Maximization might not always be the most appropriate model upon which to base resource allocation natural resource management decisions. Other *economic* decision-making models include Pareto efficiency analysis, satisficing, and any type of voting-based process. Pareto efficient resource allocations are defined as those where reallocation of resources to make one individual (or Park) better off necessarily results in making one or more individuals (or Parks) worse off. Although Pareto efficient allocations are efficient, they are not necessarily desirable. For example, if all resources are allocated to a single park it is a Pareto efficient solution, though neither equitable nor desirable. However, the process of utility assessment in welfare maximization by design eliminates Pareto *inefficient* solutions and those solutions that are unreasonable. Decisions based on Pareto efficiency might be applicable in situations where the decision to include one or more partners in a potential program is also being evaluated (i.e., does it make sense to allocate monitoring resources to all of the parks within the network?).

Satisficing, also called MiniMax, is in essence the opposite of welfare maximization. It is based on minimizing harm of those among whom resources are to be shared. This model might be particularly well suited in situations where resources are to be shared among adversarial individuals or groups where common ground cannot be easily found.

Lastly, any voting mechanism can also be used, but it is important to recognize up front that such mechanisms are always politically rather than efficiency driven. As a result, the methods used to conduct the voting will drive the outcome rather than the overall goals. However, voting methods are particularly well suited for situations in which all (or none) of the alternatives being considered are reasonable solutions that if selected would satisfy all voting parties and meet the goals of the program. The methods we propose might in fact require Parks to rely on voting to select from alternative programs, but the process is designed to ensure that all of the choices represent “best” options that meet all of the programmatic goals.

Expanding the Public Health Metaphor

The NPS Vital Signs monitoring program is based on a public health metaphor whereby the goal is to measure the "health" of the ecosystem. Although ecosystem health is a loaded term that at best is undefined, and at worst cannot be defined, a reasonable assumption is that managers need to be able to identify when systems are in a poor health.

Like blood pressure, body temperature, or heart rate are for medicine, ecosystem vital signs are those indicators that help identify when portions of the ecosystem are in poor or even declining health. However, medical monitoring really has four types of measurements: vital signs / early indicator monitoring, case history investigations, diagnostic assessments, and recovery monitoring.

To take the public health metaphor to its logical conclusion, three types of data collection might be considered in an integrated monitoring program. This multi-tiered approach would include:

1. <u>Vital Signs Monitoring</u> that is specifically targeted toward identifying whether or not the ecosystem is in poor or declining health.
2. <u>Case History Evaluations</u> that assess the health of the ecosystem based on a variety of indicators and provide hypotheses as to potential root causes of environmental degradation.
3. <u>Diagnostic Sampling</u> that identifies and quantifies the magnitude, extent, and impacts of stressors on environmental systems, and the remedies for those stressors.

All three types of monitoring are required to provide a foundation of information to support adaptive management of natural resources. Using a welfare maximization model as described herein allows for the ability to monitor at both the "Vital Signs" and "Case History" levels, and by doing so provides a framework to implement additional diagnostic studies when necessary. Such a monitoring framework is a critical need in an adaptive monitoring framework.

Monitoring Within an Adaptive Management Framework

Because the NPS monitoring program is mandated to provide information relevant to management of natural resources at the Park level, programs need to be based around both identifying when ecological changes occur and determining likely causes of those changes. This necessarily means that programs must be designed at the least to provide early warning indicators (Vital Signs) as well as place indicator data in a larger context (landscape, land management, etc.), preferably within a framework for more intensive diagnostic sampling.

Program Expansion
The model provides a tool for basing requests for additional funds by allowing the Network to defensibly argue that if the program receives X dollars, it will be able to implement Y additional indicators that would answer Z questions of importance to parks. Ideally, the initially-selected suite of indicators should be based in part with any anticipated programmatic expansions during the implementation period.

Program Review
During five-year program reviews assumptions that went into the model should be checked. For example, this is an opportune time to recheck the park preferences for answering monitoring questions, updating indicator applicability matrices, estimated costs, and incorporate any new protocols that have been developed or identified.

Protocol Development
One potential use of funds is to invest in improving monitoring methodologies or developing new protocols entirely. In this model, the long-term ability to effectively *answer* a monitoring question is of higher importance than the long term implementation of a protocol. Therefore, it is to the program's advantage to change, update, or throw out protocols that do not sufficiently answer their intended questions or if better more efficient methods can be identified.

Partnership Identification
In much the same way that protocol development can be used as a strategy to improve program efficiency, the

model can be used to direct priorities for identifying partners to implement the program. Partners can potentially aid in the collection, analysis, or reporting of individual indicators, therefore reducing costs to the program.

Research

A second potential use of funds is to develop ways to answer more questions with any given indicator or group of indicators. Research dollars in this context would be focused on better understanding linkages among ecosystem components, agents of change, and expected responses, and identifying indicators that correspond to those linkages. The result of such research would be to increase the utility of any given indicator and would therefore make the indicator more likely to remain in future alternative selections.

Inventories – Synoptic Studies

Additional baseline inventories or synoptic studies that focus on a particular component of the ecosystems during any point in time potentially provide a wealth of information that can be useful for modifying existing priorities.

The use of a welfare maximization process has several advantages over other options, primarily because it provides a framework adaptation in the face of changing priorities. Because the model is explicitly tied to both budget constraints, and end-user priorities it allows for the exploration of scenarios where budgets increase, priorities change, partners are added or removed, or new methods or protocols are developed. A decision-making tool that is explicitly designed to make comparisons among potential management options is a critical and often lacking need for resource managers. Application of this model should prove to be a useful foundation not only for monitoring program design, but also for other aspects of natural resource management

Figures

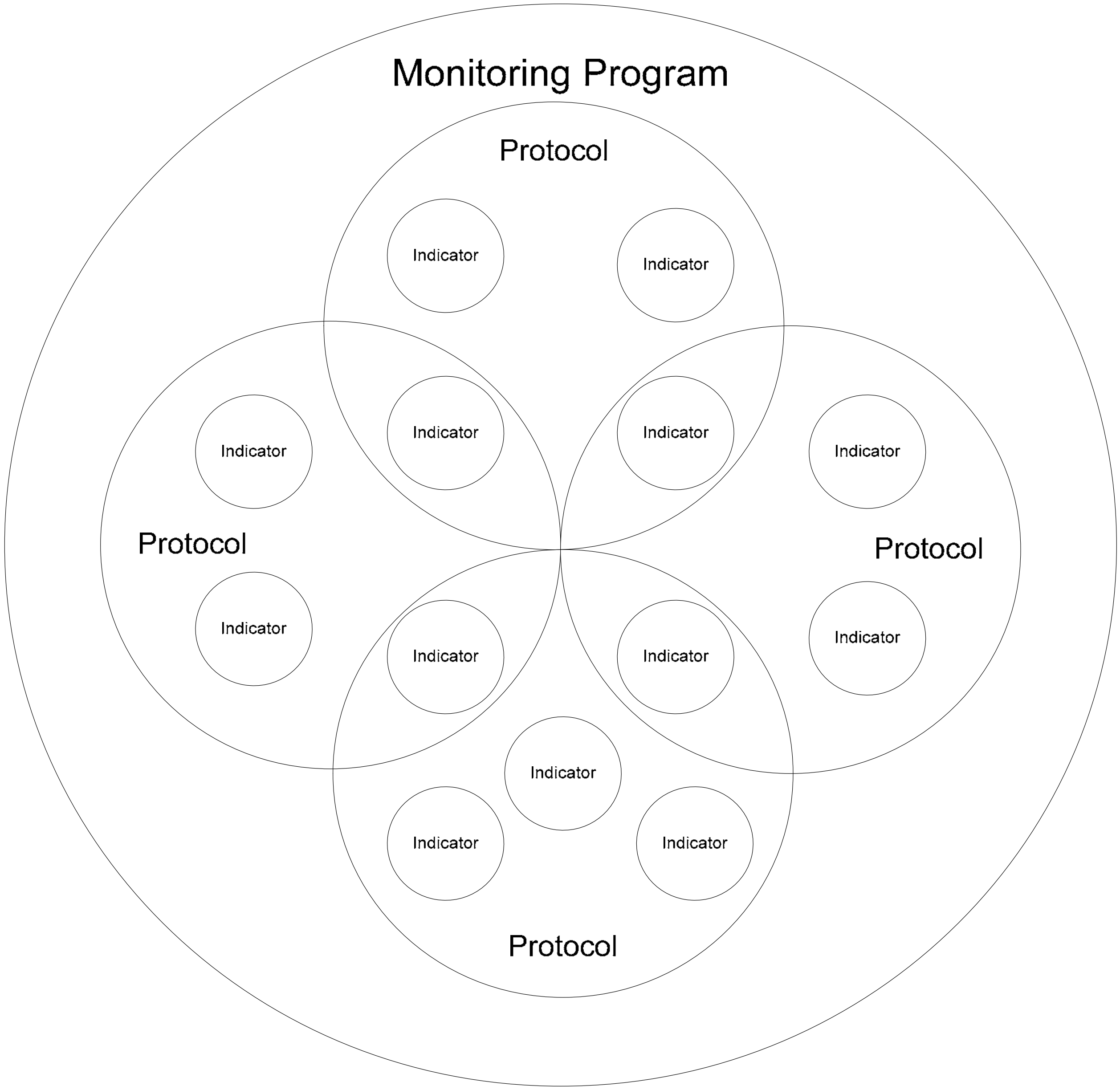


Figure A4-1. Hierarchy of indicators and protocols within an integrated monitoring program.

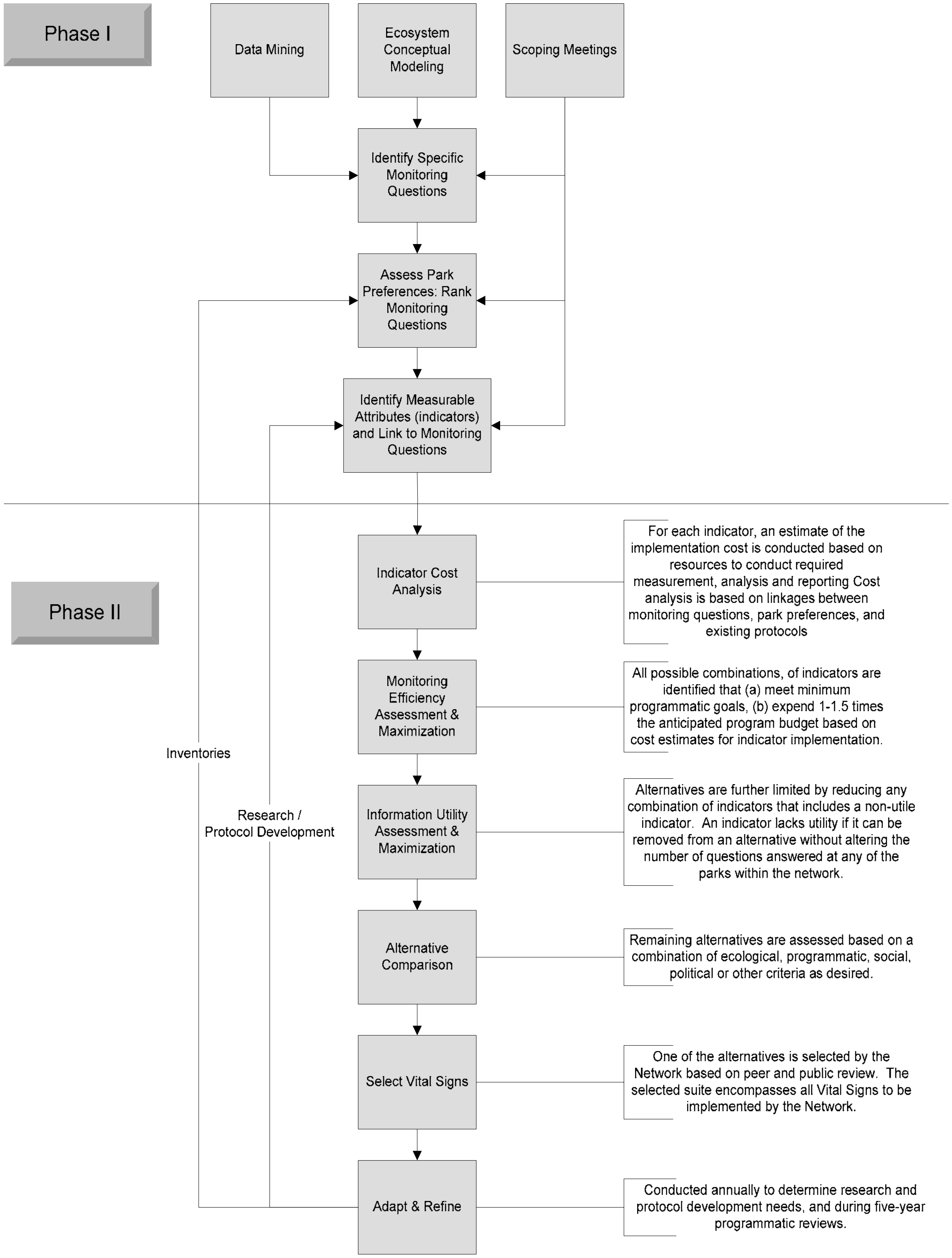


Figure A4-2. Implementation process for developing options for a Vital Signs Monitoring Program.

Tables

Table A4-1. Comparison of attributes of vital signs selection methods.

Vital Sign Selection Method	Prioritization of…	Choices Driven by…	Final Decisions based on…
BOGSAT	Indicators	Expertise / Knowledge of those at table	Consensus
Criteria Matrices	Indicators	Expertise / Bias of those applying Criteria	Highest Ranking Indicators, Consensus
Delphi	Indicators	Options included in software; expertise bias is controlled by facilitator	Highest Ranking Indicators, Consensus
Analytic Hierarchy Process (AHP)	Monitoring Questions or Indicators through multiple pairwise comparisons	Expertise / Bias of those evaluating pairwise comparison between questions or indicators	Highest Ranking Indicators, Consensus
Welfare Maximization	Monitoring Questions	End-User Needs, Economics	Alternative Comparison, Consensus

Table A4-2. Characteristics of effective monitoring variables (modified from National Park Service 2000;Jackson, Kurtz, and Fisher 2000;Kurtz, Jackson, and Fisher 2001;Dale and Beyeler 2001).

Relevant to Management Concerns and Ecological Resources

Address monitoring questions of interest

Have known linkages to ecological function or critical resource of interest

Are at appropriate scales to answer specific monitoring questions

Are integrative in space and time, so that the full suite of variables provides assessment of the entire system of interest

Applicable for Use in an Monitoring Program

Are easy and practical to measure

Are non-destructive or low impact to measure without disturbing the monitoring site

Are measurable using standard well-documented methods

Generate data that are compatible with other systems, partners, or programs

Are cost-effective to measure

Responsive to Anthropogenic Stress

Have known sampling and measurement error

Have low natural variability

Have predictable variability in time and space

Are sensitive to anthropogenic stressors to target resources, while having predictable and limited sensitivity to other factors such as natural variations or disturbances

Interpretable and Useful for Environmental Decision-making

Respond to stress predictably

Are anticipatory: signal impending change in the ecosystem before substantial degradation occurs

Are linked to management decisions; predict changes that can be averted or can result from future or past management actions

Have known or expected thresholds of response that delineate acceptable from unacceptable ecological conditions

Can be communicated to managers and the public

Table A4-3. Criteria for prioritizing potential monitoring questions.

Rank	Park Question	Examples	Examples (For T&E Species)
5	Mandated (for the Park). The park is required to meet specific monitoring objective as per legal or contractual obligations.	• Anything directly or explicitly mentioned in Park legislation or current / future management plans. Examples might include the size and impacts of horse populations at CUIS, water quality trends at CHAT, etc.	• Monitoring red cockaded woodpeckers. If breeding pairs are present on the park, required under the recovery plan to conduct 100% census of population on an annual basis.
4	Mission Critical. The Park should meet this objective to effectively manage its resources. Meeting this objective will provide information relevant to multiple resource issues.	• Success of NR Management, such as fire effects monitoring.	• T&E Species that are known to breed on NPS-managed lands, populations are in decline or critical, and Park has responsibility for managing those populations.
3	Mission Support. Meeting the monitoring objective would provide information that would help the Park to better manage its resources, but is not necessary. Provides information that will influence one or more management decisions. Meeting this objective will provide information relevant to multiple resource issues.	• Trends in external / adjacent land use • Trends and impacts of Air Quality (for some parks) • Habitat fragmentation	• T&E Species that are known to exist within park boundaries. Documentation of changes to populations (or lack thereof) would influence management or policy decisions.
2	Answering this question is of interest to the Park, but is not necessary for natural resource management. Effectively answering this question through a monitoring program might or might not shed light on multiple resource issues.	• Research • Biological Inventories • Protocol Development	• Park is in range of species, but occurrence in Park is unknown or undocumented. • Species known to migrate over, but not necessarily in park lands.
1	Not the responsibility of the Park.	• Marine Fisheries at CAHA (perhaps).	• N/A
0	Not applicable to the Park.	• Estuarine processes at HOBE	• Species range and park boundaries do not overlap.

Table A4-4. Suggested indicator characteristics for comparing alternative Vital Signs Monitoring programs.

Indicator Characteristic	Description	Potential Program Goal
Ecosystem Component	Structure: Habitats, and qualities of those habitats such as fragmentation. Function: Energy flow, nutrient dynamics, disturbance. Composition: Species diversity, trophic guilds, reproductive guilds.	Balance of indicators that measure structure, function, and composition
Conceptual Model Category	Agents of Change (leading indicators): Natural or anthropogenic factors that cause a change in the quality or quantity of target resources within the ecosystem. Target Resources: Structural, functional or compositional components of the ecosystem of interest. Expected Responses (lagging indicators):	Balance of indicators that includes agents of change, target resources, and expected responses.
Spatial Scale of variability		Indicators that span a wide variety of spatial scales.
Time Scale of variability		Indicators that span a wide variety of time scales.
Social-Political Desirability	Environmental Education Opportunities: Partnership Development:	Indicators that individually or in total provide information for a variety of non-target uses while at the same time do not inhibit the overall legitimacy of the program.

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